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DESIGN AND DEVELOPMENT OF A SMART TWO FINGERED ROBOTIC GRIPPER USING SHAPE MEMORY ALLOYS

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ABSTRACT

A major challenge in current soft robotics domain is the need for a light weight, yet flexible end effectors. Due to the increase in the usage of functional materials in mainstream design and applications, an adaptable end effector which can grip and manipulate materials with different densities and mechanical qualities is a necessity for the near future. This paper aims at designing and developing a smart two fingered robotic gripper using shape memory alloys for actuation. This research was intended to study the properties of SMA material with a scope in gripping force for soft robotics and medical robotics fields. A two fingered robotic gripper was fabricated with two sets of SMA wires fastened and supported by using 3D printed bridges. The actuation of the system was given through external power supply. The gripping force on 3 geometries: cube, cylinder and cuboid were calculated and the entire setup is automated to detect components, provide specific gripping force and the automated manoeuvring the object was studied. Experimental results showed better adherence with the appropriate gripping force for each geometry and thus better adaptability to geometry and material.

KEYWORDS: SMA, Soft Robotics & Gripper

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Original Article

INTRODUCTION

Shape memory alloys are materials, which are known for their unique property of returning to a predesigned shape or form when they are subjected to heat. When these materials are treated to their transformation temperature, the deformation form gets trained and after repeated training, the material will deform to the trained position. The phase changes from Martensite to Austenite during the transformation temperature and goes back Marten site upon losing heat. This process is called Shape Memory Effect (SME).

This feature is used to manipulate the SMAs in various forms to varying characteristics. SMAs can be used as tendons to add support and strength to continuum robots. David Camarillo et al. modelled a catheter with SMA spine and performed mechanical experimentation which matched the modelling assumptions [1].

The most common shape memory alloy is made of Nickel and Titanium (NiTi). There are other composites and alloys that demonstrate SME. Wei Wang et al. made super soft composites shape memory actuators by embedding Ni-Cr alloy, shape memory wires and fusible alloy in soft composites to make them achieve shape memory effect [2].

Junfeng Li et al. had modelled and created a SMA gripper using Cosserat theory to study its variable stiffness characteristics, so it can be used to grip objects with different stiffness [3]. This method is considered along with the research method used by Ms. Chavan Madhura et al. They developed an SMA gripper by actuating the fingers with the tension provided by SMAs which become spring elements when energized along with the help of a torsional spring [4]. A simpler gripper with a SMA spring element was used to actuate a mechanical linkage system constituting the opening and closing mechanism of the gripper was developed by Nafise Faridi Rad et al. in their paper [5]. This helped in the basics for developing our spring element in the gripper system. A. A. León Baldelli et al. modelled the super elasticity of the shape memory alloys using a gradient approach to observe localised evolutions of a super elastic SMA model [6]. The control of the shape memory alloys to form a gripper for open mode operation was tested and discussed in the work by S. Krishna Chaitanya et al., where the gripper was designed to open at a specific angle which was achieved only through the control of the SMAs, while the uncontrolled gripper displayed variations in the opening (actuating) angle [7]. S. Krishna et al., also developed a sliding mode control for their gripper and tested the open loop and closed loop behaviour of the gripper [8]. The same modes were fabricated and tested with a single set of SMA wire in another paper of theirs [9].

The present work aims at designing and developing an SMA gripper, measure the gripping forces required to maneuver three objects made of wood and different geometries. The measured gripping force values must be corresponded to current value and the system must be programmed to detect object placed in the field and apply appropriate gripping force, thus automating the system. A study, similar to this paper was done to test and analyze the gripping force provided by a PID controlled DC motor actuated gripper system with force sensors (FSR type) for components with varying geometries and materials performed by Anan Suebsomran gave us insight as to what should be considered for our SMA actuated gripper system [10]. The paper by Pavel Dzitac et al. gave us insight on the considerations for end effector design and future scope to avoid, detect and avoid slippage of the object to be manipulated [11].

EXPERIMENTAL PROCEDURES

CAD Modelling

Two sets of SMA wires were used in this study. One set of the SMA wires (SMA1) were used to converge the fingers towards the object to achieve "closed" position, while the other set (SMA 2) was used to return to the "open" position.

The gripper consists of three major parts: the base, inner bracket and end effector. The base is the part which actually encases and embeds the actuating (to "closed" position) SMA mechanism. This is also the part where the supply is given to both the sets of SMA wires. The CAD model of the base is as displayed in the figure 1.

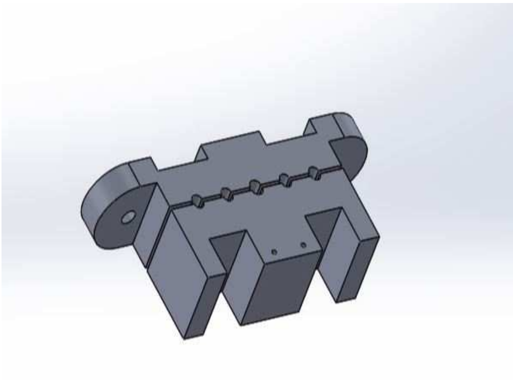

Figure 1: Gripper Base – CAD Model.

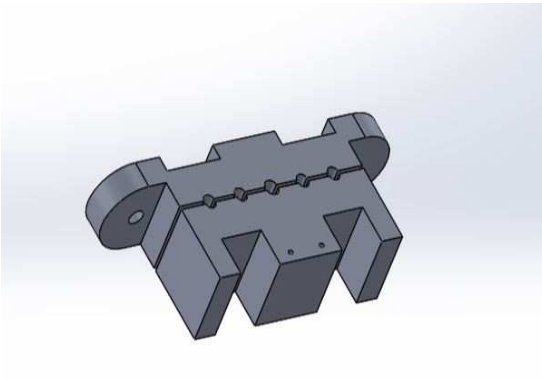

Figure 2: Inner Brackets – CAD Model.

The inner brackets were support structures which fastened the SMAs in place. The purpose of the bracket is to provide support, structure and stability to the SMA wires. A set of 4 inner brackets were used for each finger. The CAD model of the inner brackets are as shown in the *figure 2*.

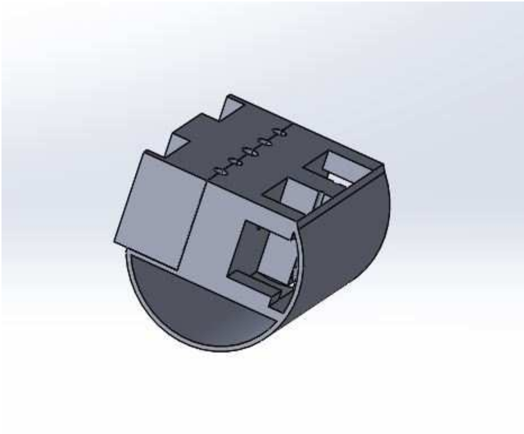

Figure 3: End Effectors – CAD Model.

Figure 4: Mounted Two Finger SMA Gripper – CAD Model.

The end effectors are the parts that actually contact the target objects. The force sensors were fixed in this part and also the connection for the SMA wires used for the retraction is provided at this position (negative of the supply). The CAD model of the end effectors were as shown in the *figure 3*.

The entire set of grippers were 3D printed, assembled and mounted on a test rig with vertical movement provided by motorized rack and pinion system. The CAD model of the assembled system were as shown in *figure 4*.

Selection and Training SMA

SMA 495 was selected for the converging and retracting sets. SMA 495 are commonly used for actuators and surgical applications. SMA 495 are Nitinol based and can be trained to be malleable or exhibit SME at boiling point of water or at temperatures trained with autoclave. The physical and shape memory properties of the SMA wires are as shown in the *table 1*.

Table 1: Physical and Shape Memory Properties of SM495 Wires

Melting Point	1310 °C
Density	6.5 g/cm^3
Electrical resistivity	76 m. ohm-cm
Modulus of elasticity	28 – 41 GPa
Coefficient of Thermal Expansion	6.6 x 10^{-6}/ °C
Shape memory Strain	≤ 8.0%
Ingot Austenite Finish (Af)	75 to 110°C

For this paper, the diameter of SMA-1s were selected to be 0.75mm, while the SMA495 wires with 1 mm were selected for SMA-2. The SMA 1 wire was coiled on a rod and then heat trained in an autoclave as seen in the figure 5, and the shape was held in place by filling the container with plaster of paris. While another set of SMA-1 wires were put to the desired “closed” position shape and heat treated. The SMA-2s were heat treated to straighten when energized.

Figure 5: SMA-1s Set to Desired Shape before it was Filled with Plaster of Paris and Heat Treated.

Fabrication of Target Objects

The three objects to be gripped and maneuvered were fabricated with wood. The wooden cube was fabricated weighing about 33.9805 g, while the cylindrical and cuboid targets weighed around 30.4688 g and 54.9472 g, respectively. The gripping force of each object were calculated theoretically, to be compared with the practical test and thus to automate the gripper system.

Gripping Force Sensing Analysis

As mentioned earlier, it was vital to calculate the gripping force for each object that was calculated and compared with the actual value to automate the system. The gripping force values were calculated theoretically, as seen in *table 2*.

Table 2: Theoretical Gripping Force Calculation for each Object

Geometry	Mass in grams	Required Gripping Force
Cube	33.9805	0.4447 N
Cylinder	30.4688	0.3989 N
Cuboid	54.9472	0.7194 N

To take the practical measurements, FSR was attached on the end effectors of the grippers, programmed and calibrated. The following schematic model was used to measure the gripping force required to manipulate the target objects as seen on figure 6. *Figure 7* shows the systematic arrangement of the SMA wires and the gripper parts, with the FSR attached to the end effector.

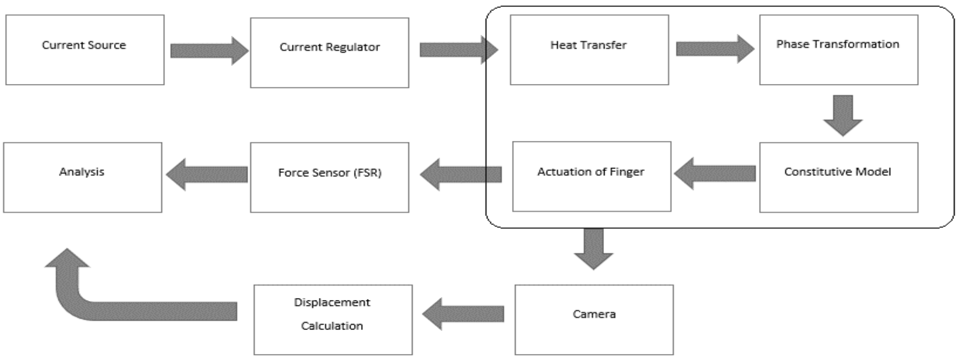

Figure 6: Schematic Model for Obtaining Gripping Force of the Target Objects.

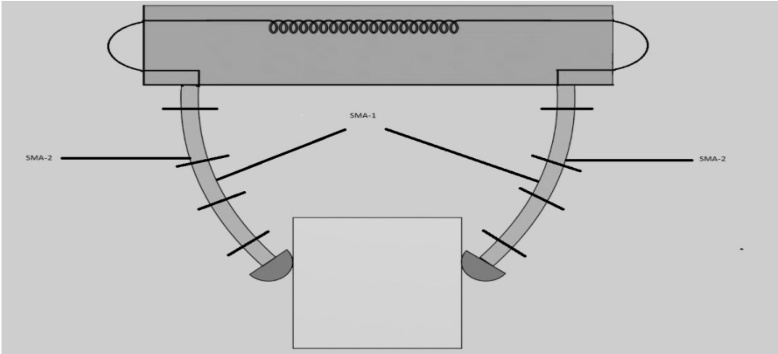

Figure 7: Schematic Diagram of SMA Wires and when Actuated to Grip a Target Object.

Automation of the Gripper

A camera or an ultrasonic sensor was used to trigger the presence of the target object in position. The Arduino board initiates the vertical movement of the gripper. The SMA1 wires were energized, once the vertical limit was reached, to initiate the “closed” position and grip the object. The calculated gripping force values along with the experimental values were to be reached to initiate the vertical return sequence as seen in *figure 8* and *figure 9*.

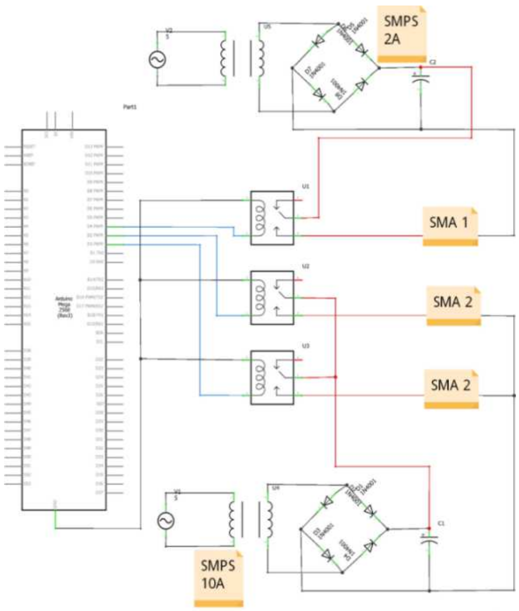

Figure 8: Schematic Diagram for Object Grasping.

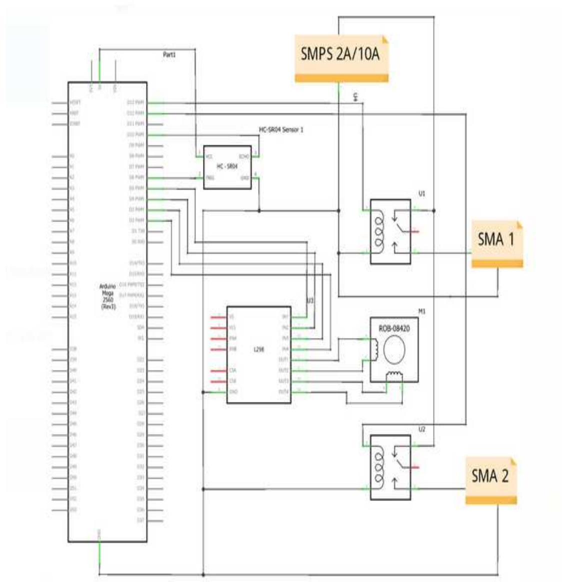

Figure 9: Schematic Diagram for Motor Control.

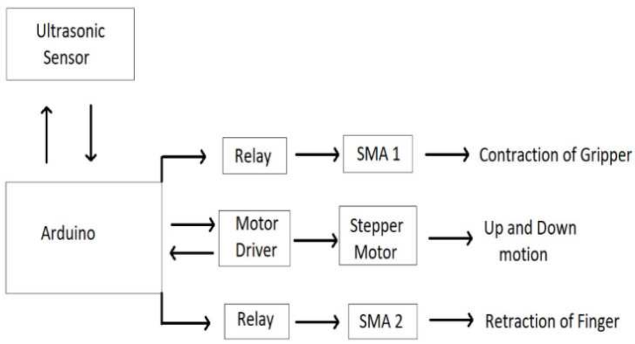

Figure 10: Schematic Diagram for Automation of Gripper.

RESULTS

Cuboid

The theoretical gripping force required and the experimental measurement values were tabulated as seen in the *table 3.* The experimental setup manipulating the cuboid can be seen in the *figure11*.

Table 3: Theoretical vs Experimental Gripping Force Values – Cuboid

Experimental (N)	Theoretical (N)
0.821	0.7194
0.792	
0.755	
0.911	
0.921	

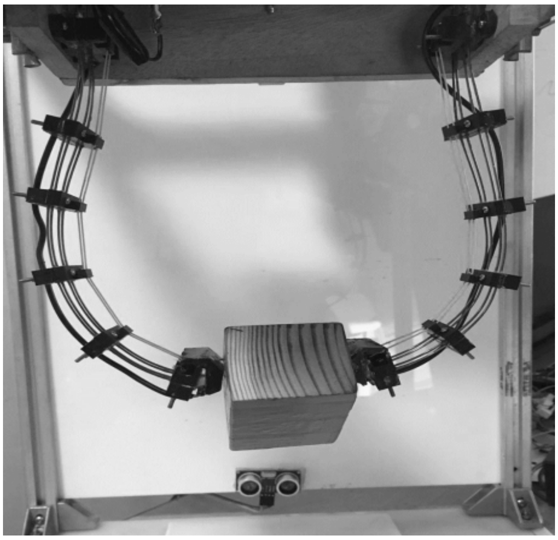

Figure 11: Automated Gripper Maneuvering the Cuboid

It can be observed from the values that the SMA wires were capable of delivering the required gripping force by adjusting the input current.

Cube

The theoretical gripping force required and the experimental measurement values were tabulated as seen in the *table 4.*

The experimental setupmanipulating the cuboid can be seen in the *figure12*.

Table 4: Theoretical vs Experimental Gripping Force Values – Cube

Experimental (N)	Theoretical (N)
0.492	0.4447
0.517	
0.493	
0.610	
0.455	

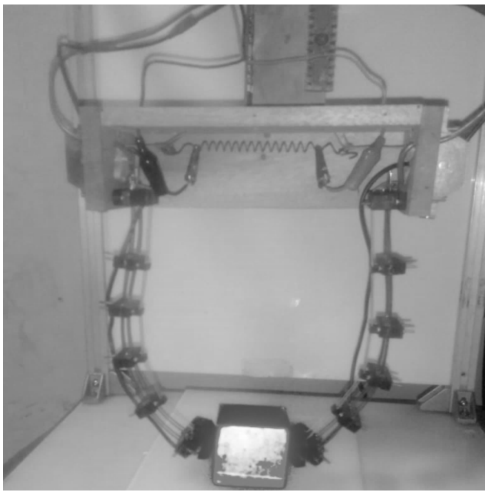

Figure 12: Automated Gripper Maneuvering the Cube

Cylinder

The theoretical gripping force required and the experimental measurement values were tabulated as seen in the *table 5*. The experimental setup manipulating the cuboid can be seen in the *figure13*.

Table 4: Theoretical vs Experimental Gripping Force Values – Cylinder

Experimental (N)	Theoretical (N)
0.420	0.3989
0.520	
0.611	
0.601	
0.432	

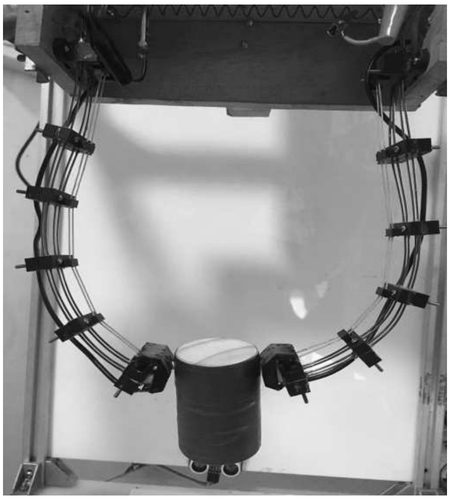

Figure 13: Automated Gripper Maneuvering the Cylinder

CONCLUSIONS

The Experimental measurements of the actual gripping force required to grip the objects were used to set the required current, and thus the entire system was automated in a pick and place perspective. But from the obtained values, it was evident that the gripping force values fluctuated mildly.

But the values and the automation of the system shows that the gripper system was capable of manipulating different geometries. As a future scope, a current supply controller can be implemented to control the variable stiffness that the grippers can provide, so they can be used to manipulate objects with variable geometries and surface hardness. This can be developed with a scope for surgical robots and soft robots.

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